

METHODS AND APPARATUS FOR COUPLING
CERAMIC MATRIX COMPOSITE TURBINE
COMPONENTS

BACKGROUND OF THE INVENTION

[0001] This application relates generally to turbine engines and, more particularly, to methods and apparatus for assembling turbine engine components that are fabricated from ceramic matrix composite materials.

[0002] Turbine engines include at least one stator assembly and at least one rotor assembly. At least some known rotor assemblies include at least one row of circumferentially-spaced rotor blades. The blades extend radially outward from a platform to a tip. A plurality of static shrouds coupled to a stator block abut together to form flowpath casing that extends circumferentially around the rotor blade assembly, such that a radial tip clearance is defined between each respective rotor blade tip and the casing or shroud. The tip clearance is tailored to be a minimum, yet is sized large enough to facilitate rub-free engine operation through the range of available engine operating conditions.

[0003] During operation, tip leakage across the rotor blade tips may limit the performance and stability of the rotor assembly. However, during operation, because the shrouds may be subjected to higher operating temperatures than the stator block, the shrouds may thermally expand at a different rate than the stator block or the fastener assemblies used to couple the shrouds to the stator block. More specifically, the differential thermal expansion may undesirably cause increased tip leakage as the operating temperature within the engine is increased. In addition, over time, the heat transfer from the shrouds and the differential thermal expansion may also cause premature failure of the fastener assemblies.

[0004] Accordingly, to facilitate reducing tip leakage caused by the differential thermal expansion, at least some known engines supply increased cooling flow past the shrouds and fastener assemblies. However, excessive cooling flow may

adversely affect engine performance. To facilitate increasing the operating temperature of the engine, and thus facilitate improving engine performance, other known stator assemblies have included shrouds fabricated from stronger or higher temperature capability materials. However, although such materials should enable the shrouds to be exposed to higher operating temperatures, the operation of the engine may still be limited by the increased thermal differential expansion rates between the shrouds and the stator block through the fastener assemblies.

BRIEF DESCRIPTION OF THE INVENTION

[0005] In one aspect, a method for assembling a stator assembly for a turbine engine is provided. The method comprises positioning a shroud fabricated from a ceramic matrix composite material adjacent to a metallic stator block, and coupling the shroud to the stator block using a coupling arrangement such that a predetermined radial clearance is defined between the shroud and a rotor assembly coupled radially inward thereof.

[0006] In another aspect, a stator assembly for a turbine engine is provided. The stator assembly includes a stator block including at least one fastener opening, a coupling arrangement, and a shroud coupled to the stator block by the coupling arrangement. The shroud includes at least one fastener opening. The coupling arrangement includes at least one fastener extending through the shroud at least one fastener opening and at least one fastener opening through the stator block. The fastener includes an external surface coated with at least one of a wear coating and a thermal barrier coating.

[0007] In a further aspect, a turbine engine is provided. The turbine engine includes a rotor assembly, and a stator assembly that includes a stator block, at least one fastener, and a shroud. The shroud is coupled to the stator block by the at least one fastener such that a radial clearance is defined between at least a portion of the rotor assembly and the shroud. The at least one fastener includes an external surface coated with at least one of a wear coating and a thermal barrier coating.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a schematic illustration of an exemplary gas turbine engine;

[0009] Figure 2 is an enlarged side view of an exemplary fastener that may be used with a turbine engine, such as the gas turbine engine shown in Figure 1;

[0010] Figure 3 is a cross-sectional view of the fastener shown in Figure 2;

[0011] Figure 4 is an enlarged cross-sectional view of a portion of a stator assembly that may be used with a turbine engine, such as the gas turbine engine shown in Figure 1, and including the fastener shown in Figure 2; and

[0012] Figure 5 is an enlarged cross-sectional schematic view of a portion of the stator assembly shown in Figure 4.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Figure 1 is a schematic illustration of an exemplary gas turbine engine 10 coupled to an electric generator 16. In the exemplary embodiment, gas turbine system 10 includes a compressor 12, a turbine 14, and generator 16 arranged in a single monolithic rotor or shaft 18. In an alternative embodiment, shaft 18 is segmented into a plurality of shaft segments, wherein each shaft segment is coupled to an adjacent shaft segment to form shaft 18. Compressor 12 supplies compressed air to a combustor 20 wherein the air is mixed with fuel supplied via a stream 22. In one embodiment, engine 10 is a 6FA+e gas turbine engine commercially available from General Electric Company, Greenville, South Carolina.

[0014] In operation, air flows through compressor 12 and compressed air is supplied to combustor 20. Combustion gases 28 from combustor 20 propels turbines 14. Turbine 14 rotates shaft 18, compressor 12, and electric generator 16 about a longitudinal axis 30.

[0015] Figure 2 is an enlarged side view of an exemplary fastener 50 that may be used with a turbine engine, such as engine 10 (shown in Figure 1). Figure 3 is a cross-sectional view of fastener 50. In the exemplary embodiment, fastener 50 is a pin, and includes an integrally-formed head portion 52, a nose portion 54, and a barrel or shank portion 56 extending therebetween. In the exemplary embodiment, head portion 52 is threaded and has a diameter D_1 that is larger than a diameter D_2 of barrel portion 56. More specifically, in the exemplary embodiment, head portion 52 is formed with a plurality of threads 60 extending outwardly from an external surface 62 of fastener 50. Threads 60 enable fastener 50 to be secured within a threaded opening (not shown in Figures 2 and 3). In an alternative embodiment, head portion 52 does not include any threads 60, but rather barrel portion 56 is threaded.

[0016] In the exemplary embodiment barrel portion diameter D_2 is substantially constant between head and nose portions 52 and 54, respectively. Moreover, in the exemplary embodiment, barrel portion 56 is un-threaded such that fastener external surface 62 is substantially smooth across portion 56. In an alternative embodiment, at least a portion of barrel portion 56 is threaded. In another alternative embodiment, barrel portion diameter D_2 is not constant across barrel portion 56. In the exemplary embodiment, barrel portion diameter D_2 is between approximately 0.25 inches and 0.3125 inches.

[0017] Nose portion 54 is gradually tapered inward from barrel portion 56 such that a diameter D_3 at an inner end 64 of fastener 50 is smaller than barrel portion diameter D_2 . Moreover, in the exemplary embodiment, nose portion 54 curves inwardly such that portion 54 has a bullnose-shaped cross-sectional profile.

[0018] A sealing flange 70 extends radially outward from barrel portion 56 such that a pair of opposed faces 72 and 74 are defined. In the exemplary embodiment, faces 72 and 74 are substantially parallel and each is substantially perpendicular to a centerline axis of symmetry 76 extending through fastener 50. Moreover, in the exemplary embodiment, sealing flange 70 is formed integrally with fastener 50. In an alternative embodiment, fastener 50 does not include a sealing flange 70.

[0019] Sealing flange 70 is spaced a distance d_4 from head portion 52 such that an annulus 80 is defined between sealing flange 70 and head portion 52. In the exemplary embodiment, annulus 80 has an external diameter D_5 that is smaller than barrel portion diameter D_2 and is substantially constant therethrough.

[0020] A cooling passageway 90 is defined within fastener 50 and extends through barrel and nose portions 56 and 54, respectively. Cooling passageway 90 has a diameter D_6 measured with respect to an inner surface 92 of fastener 50. In the exemplary embodiment, diameter D_6 is substantially constant along a length L_1 of passageway 90.

[0021] Cooling passageway 90 extends from an inlet 94 to a discharge outlet 96. Inlet 94 extends generally radially from fastener external surface 62 to passageway 90 and enables cooling fluid to be supplied to fastener passageway 90 from a cooling circuit (not shown in Figures 2 and 3) when fastener 50 is secured within the threaded opening. More specifically, in the exemplary embodiment, inlet 92 is defined within annulus 80. Outlet 96 extends substantially axially from fastener external surface 62 to passageway 90 and enables cooling fluid to be discharged from fastener passageway 90 when fastener 50 is secured within the threaded opening. More specifically, in the exemplary embodiment, outlet 96 is substantially concentrically aligned with respect to fastener 50, and extends axially inward from fastener end 64.

[0022] Fastener external surface 62 is coated with a wear coating and/or a thermal barrier coating (TBC) that facilitates improving the wear characteristics of fastener 50 and/or thermally insulates fastener 50, as described in more detail below. For example, in one embodiment, fastener 50 is fabricated from a metallic alloy material, such as L605, commercially available from Haynes International, Inc., Kokomo, Indiana. More specifically, fasteners 50 are fabricated from metallic materials which facilitate fasteners 50 operating with a desired fracture toughness, and a demonstrated reliability.

[0023] Moreover, in at least some embodiments, the coating also facilitates reducing oxidation of fastener 50. For example, in the exemplary embodiment, fastener 50 is coated with a wear or thermally insulating bond coat, such as a NiCrAlY, and is then further coated with an external oxidation resistive coating, such as Deloro-Stellite's Tribaloy T-800. The gradual transition of nose portion 54 facilitates enhancing the coating adhesion to fastener 50, as more radical transitions may result in loss of coating during, or shortly after, the coating process. Accordingly, as described in more detail below, the fastener coating enables fastener 50 to be utilized in increased stress environments and/or in increased operating temperatures, without requiring that fasteners 50 be fabricated from more expensive or brittle materials that are more temperature or wear resistive.

[0024] Figure 4 is an enlarged cross-sectional view of a portion of a stator assembly 100 that may be used with a turbine engine, such as gas turbine engine 10 (shown in Figure 1). Figure 5 is an enlarged cross-sectional schematic view of a portion of stator assembly 100. Specifically, stator assembly 100 includes a stator block 102 that forms a portion of a casing within engine 10, and a shroud 104. In one embodiment, stator casing 100 extends circumferentially around a rotor assembly, such as turbine 14.

[0025] In the exemplary embodiment, stator block 102 is fabricated from a metallic material and is formed with a plurality of leading edge fastener openings 110, a plurality of trailing edge fastener openings 112, and a shroud slot 114. Fastener openings 110 are circumferentially-spaced across a leading edge side 116 of stator block 102, and openings 112 are circumferentially-spaced across a trailing edge side 118 of stator block 102. Openings 110 and 112 are each sized to receive a fastener 50 therein to enable shroud 104 to be coupled to stator block 102, as described in more detail below.

[0026] In the exemplary embodiment, fasteners 50 include a plurality of pins 120 and a plurality of bolts 122. Pins and bolts 120 and 122, respectively, are substantially similar and each includes a wear or thermally insulating coating, internal cooling passageway 90, and head, nose, and barrel portions 52, 54, and 56,

respectively. Unlike pins 120, threads 60 are not formed within bolt head portion 52, but rather instead each barrel portion 56 is threaded. In addition, bolt barrel portion 56 is stepped such that at least one segment 124 of barrel portion 56 has an external diameter D_8 that is sized differently than the remaining barrel portion diameter D_2 . For example, in the exemplary embodiment, barrel portion diameter D_8 is larger than barrel portion diameter D_2 .

[0027] A sealing face 130 is defined at the intersection created between barrel portion 56 and segment 124. Accordingly, in the exemplary embodiment, bolts 120 do not include sealing flange 70, but rather, when bolts 120 are fully secured within openings 112, sealing flange 70 is secured in sealing contact against stator block 102, and more specifically, against a sealing boss 132 extending outwardly from stator block 102. Each sealing boss 132 circumscribes each opening 112, and extends outwardly from stator block to form a mating surface that receives sealing face 130 in sealing contact.

[0028] Bolt cooling passageway 90 extends between inlet 94 and discharge outlet 96. However, unlike pins 120, bolt cooling passageway inlet 94 is defined within bolt barrel portion 56.

[0029] In the exemplary embodiment, each stator block opening 112 extends radially inward from an external surface 140 of stator block 102 and has a diameter D_{10} that is substantially constant therethrough. More specifically, opening 112 has a length L_3 that is longer than a length L_5 of bolt barrel portion 56. Accordingly, when bolt 120 is threadedly coupled within opening 112, a hollow space 142 is defined between bolt inner end 64 and a radially inner end 144 of opening 112.

[0030] Each stator block opening 110 also extends radially inward from stator block external surface 140 and is bifurcated such that a first portion 150 of opening 110 is defined within a radially outer portion 152 of stator block 102 that is adjacent to shroud slot 114, and a second portion 154 of opening 110 is defined within a radially inner portion 156 of shroud block 102 that is adjacent to shroud slot 114. In the exemplary embodiment, opening first portion 150 has a diameter D_{14} that is

slightly larger than pin head diameter D_1 , an opening second portion 154 has a diameter D_{16} that is smaller than diameter D_{14} and is slightly larger than pin barrel portion diameter D_2 . More specifically, opening first portion 150 extends from external surface 140 to an end wall 160 that defines a portion of shroud slot 114, and opening second portion 152 extends through end wall 160 and through stator block radially inner portion 156. Accordingly, when pin 120 is securely coupled within opening 110, seal flange 70 contacts end wall 160 in sealing contact, and pin barrel portion 56 is inserted through opening portion 150 and at least partially through opening portion 152. Moreover, when pin 120 is securely coupled within opening 110, pin head 52 is recessed within opening 110 such that an outer surface 170 of pin head 52 is substantially co-planar with the portion of stator block external surface 140 adjacent to opening 110.

[0031] Each stator block opening 110 and 112 is coupled in flow communication to a cooling fluid supply source through a cooling circuit 180. Cooling circuit 180 includes a plurality of supply slots 182 that each supply cooling air into a respective opening 110, and a plurality of supply slots 184 that each supply cooling air into a respective opening 112. Cooling circuit 180 also includes a plurality of discharge slots 186 that each route discharged cooling air from a respective opening 112.

[0032] Shroud 104 includes a plurality of fastener openings 190 which extend from a radially inner side 192 of shroud 104 to a radially outer side 194 of shroud 104. More specifically, openings 190 include a plurality of fastener pin openings 196 that are sized to receive a portion of a respective pin 120 therethrough, and a plurality of bolt openings 198 that are sized to receive a portion of a respective bolt 122 therethrough. More specifically, openings 196 are sized to receive pin barrel portion 56 therethrough, and openings 198 are sized to receive pin barrel portions 54 and 124 therein such that head portion 52 remains external to opening 198.

[0033] When assembled, shroud 104 is suspended from pins and bolts 120 and 122, respectively. More specifically, when stator assembly 100 is fully assembled, a downstream side 200 of shroud 104 is coupled to stator block 102 by

bolts 122 such that bolts 122 are inserted through shroud openings 198 prior to being threadingly coupled to stator block 102 within block openings 112. Accordingly, when bolts 122 are secured to block 102, shroud downstream side 200 is suspended from bolt barrel portion 124 between bolt head portion 52 and stator block external surface 140. Furthermore, when stator assembly 100 is fully assembled, an upstream side 202 of shroud 104 is coupled to stator block 102 by pins 120 such that shroud 104 is suspended by pin barrel portion 56 within shroud slot 114. Accordingly, when coupled to stator block 104, a radial clearance is defined between shroud 104 and rotating members of a rotor assembly, such as

[0034] Shroud 104 is fabricated from a ceramic matrix composite (CMC) material that enables shroud 104 to be exposed to, and to sustain, higher operating temperatures than fasteners 50 or stator block 102. Accordingly, a rate of thermal expansion for shroud 104 may be different than a rate of thermal expansion of fasteners 50 or stator block 102 during engine operation. The pin and bolt concepts described herein, permit fasteners 50 to accommodate the difference in thermal expansion rates between stator block 102 and shroud 104. More specifically, because a width W_3 of shroud 104 is smaller than a width W_5 of shroud slot 114, shroud 104 may slide axially within slot 114 to accommodate differential thermal expansion such that a radial clearance defined between shroud 104 and a rotor assembly, such as turbine 14. Moreover, the pin and bolt concepts described herein also enable fasteners 50 to operate within the thermal environment sustained by ceramic matrix composites, without melting. Notably, the wear or thermal coating across fasteners 50 facilitates enabling the material used in fabricating fasteners 50 to operate beyond its un-coated melting point. Moreover, because the coating provides both thermal insulation and oxidation resistance, the coating facilitates extending a useful life of fasteners 50.

[0035] In addition, when fully assembled, cooling fluid is supplied internally to fasteners 50 during engine operation. Specifically, cooling fluid is supplied to stator block openings 110 through supply slots 182. As the fluid enters openings 110, annulus 80 is pressurized by the cooling fluid prior to the fluid being channeled into pin cooling passageway 90 through inlet 94. The cooling fluid flows

through pin cooling passageway 90 and is discharged through outlet 96 and flows external to stator block 102. More specifically, the cooling fluid flowing through pin cooling passageway 90 facilitates maintaining an operating temperature of pin 120 within acceptable limits.

[0036] In addition, cooling fluid is supplied to stator block openings 112 through slots 184. Fluid supplied through slots 184 is channeled into bolt cooling passageway 90 through inlet 94. The cooling fluid flows through pin cooling passageway 90 and is discharged through bolt cooling passageway outlet 96 wherein the fluid enters space 142 prior to being discharged externally to stator block 102 through discharge slots 186. More specifically, the cooling fluid flowing through bolt cooling passageway 90 facilitates maintaining an operating temperature of bolt 122 within acceptable limits.

[0037] The above-described fasteners provide a cost-effective and highly reliable method for coupling a ceramic matrix composite shroud to a metallic stator block.. Accordingly, the combination of the ceramic matrix composite shroud and the fasteners described herein, facilitate enabling the turbine to operate at higher temperatures, thus improving thermodynamic efficiency of the turbine. The fasteners described herein accommodate the differential thermal expansion between the shroud and the stator block, while maintaining the radial clearance defined by the shroud. As a result, the fasteners facilitate extending a useful life of the stator assembly and improving the operating efficiency of the gas turbine engine in a cost-effective and reliable manner.

[0038] Exemplary embodiments of stator assemblies and turbine engines are described above in detail. The stator assemblies are not limited to the specific embodiments described herein, but rather, components of each stator assembly may be utilized independently and separately from other components described herein. For example, each stator assembly component can also be used in combination with other turbine engine components, and is not limited to practice with only stator assembly 100 as described herein. Rather, the present invention can be

implemented and utilized in connection with many other high temperature attachment configurations.

[0039] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.